

**NRF REVISED FINAL PROPOSAL 2021**

**THEMATIC AREA: SCIENCE AND ENGINEERING (SE)**

**TITLE: DEVELOPMENT OF AN ENERGY-EFFICIENT MINIATURIZED  
GLOBAL POSITIONING SYSTEM RECEIVERS FOR LIVESTOCK TRACKING  
APPLICATION**

## **EXECUTIVE SUMMARY**

Livestock rustling and farmland encroachment are primary drivers of insecurity in most parts of Africa, including Nigeria. Some states, especially in Northern Nigeria are engulfed by unprecedented crises that precipitated the current state of banditry and kidnappings. This research work leverages the use of technology to combat cattle theft (rustling) and farm encroachment thereby mitigating the perennial loss of lives and properties in the country. The research proposal will be implemented in stages.

The first stage of this research is the development of a novel energy-efficient miniaturized Global Positioning System (GPS) receiver (also called tracker) with embedded ZigBee module. The miniaturization process entails reducing an existing tracker from a previous research from 4.5 x 4.5 cm to 0.45 cm x 0.45 cm using 7 or 5 nanometers fabrication process and System-on-Chip (SoC) design. Miniaturization ensures the tracker is concealable on livestock in order to frustrate both rustling and farmland encroachments. The proposed energy-efficiency system involves speeding up the computation of GPS geolocation by incorporating a high speed processor with the GPS. Faster processing translates to shorter draw on battery energy. Two methods are proposed to manage the energy utilized by 3G/ 4G LTE to transmit computed geolocation data. The first approach uses a low-power ZigBee to create a self-organizing wireless sensor network (WSN) for cooperative transmission of computed GPS coordinates to the network's personal area network (PAN) coordinator. The second approach adopts predictive sleep mode of ZigBee devices at the medium access control (MAC) layer. This later approach ensures each device will broadcast her coordinates to the PAN coordinator at an agreed time when the channel is free. The proposed system will be evaluated based on battery lifespan and frequency of reported coordinates. Battery lifespan performance is projected to last 2 years without recharging.

The second stage of the research is the development of a mobile phone application that will enable users to create virtual fences (geo-fences) around farmlands or restricted areas. Geo-fences will automatically trigger an alarm by issuing notification that a particular farm/area is either about to be encroached upon by cattle or is currently being encroached. Notification is done by either automatic voice call or SMS.

At the end of the research, two academic papers will be published in reputable journals. Workshops and presentations to relevant institutions and authorities will be carried out to showcase the importance of the proposed system and to demonstrate its functionalities.

### **Short Term Goals**

Concealable trackers and geo-fences will discourage both livestock rustling and farmland encroachment because rustled livestock can be easily tracked and recovered, while cattle approaching farmlands can be detected and ordered to stay away by calling the herder or cattle owner.

### **Long Term Goals**

- i. Concealing trackers on military armaments will discourage compromised security officers from providing arms to bandits, since weapons can be tracked and recovered.
- ii. Concealing trackers on humans and assets will discourage kidnappings and thefts of assets, since anyone/any asset with a concealed tracker can be easily located and recovered.
- iii. The project will provide job opportunities to those who wish to install trackers on vehicles, cargos or help farmers to map their farmlands.

The estimated Budget for the realization of the project is Twenty Million Naira (20,000,000.00k).

**KEYWORDS:** Livestock Tracking, Farmland Monitoring, Energy Efficiency, Energy Conservation, Miniaturization.

**PROJECT DURATION:** 24 months

## **1.0 GENERAL BACKGROUND OF THE RESEARCH**

### **1.1 Background of the Research Project**

Thousands of farmers and herders have lost their lives and sources of livelihood, while additional thousands have been displaced as a result of ongoing conflict between herders and farmers [1]. Unfortunately, these attacks are contributing to the escalating prices of food stuffs in various parts of Nigeria [2][12]. Meanwhile, various attempts by States and Federal governments to quell the violence by spending billions in direct payments to herd owners [3] and farmers [4] or in settling up ranches and Rural Grazing Area (RUGA) [5][6] have not yielded any good result. The principal reasons for these conflicts are accusations of land encroachment and destruction of agricultural produce leveled by farmers against herdsmen's cattle. Similarly, herdsmen have leveled accusation of cattle rustling against people residing in their host community [7]. Therefore, a careful analysis of the conflict's root causes exposes the need for scientific resolution of the conflict through using the right technology, coupled with political will (power) of policy makers to back scientific solutions to resolving the conflict.

A simple method of providing hard evidence of rustling or farm encroachment is by using Global Positioning System (GPS) receivers (or trackers) to:

1. Identify the current location of rustled cattle by viewing cattle location on our web application [8][9].
2. Know the identity of cattle that encroached into a farmland by playing back historical records of cattle movement within the farm area [8][9].

The proposed research conceals energy-efficient miniaturized trackers on participating cattle. The overall system provides dynamic cattle tracking and monitoring solutions at any geo-location. Similarly, the work proposes the creation of virtual fences (geo-fences) around farmlands. Geo-fences will automatically trigger an alarm and notify both the farmer and the cattle owner of imminent encroachment via voice call or SMS.

Research implementation would provide means of combating rustling, and detecting and preventing farmland encroachment. It will mitigate the perpetual loss of lives and properties since herders and farmers know that their sources of livelihood are protected. This will definitely boost national agricultural productivity and safety in the country.

## **1.2 Aim and Specific Objectives of the Research Project**

The overall objective (aim) is to miniaturize and develop energy-efficient algorithm for GPS receivers and deploy them on cattle.

The specific objectives are as follows:

- i. To miniaturize trackers to the size reasonable for concealment on cattle
- ii. To develop and test energy-efficient algorithms for the proposed GPS receivers
- iii. To develop geo-fencing software for mobile phones.

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## **1.3 Statement of the Problem**

Aggrieved farmers who lost farmlands or farm produce to cattle and herdsmen who lost cattle to rustlers often take law into their hands by avenging themselves [11]. This situation increases the likelihood of retaliatory attacks, leading to further loss of lives, properties, insecurity, and a sharp increase in prices of foodstuffs and livestock [2][12]. Efforts by concerned government organs to resolve these conflicts are not promising, despite billions of money expended in direct compensation or in provision of infrastructures [3][4][6][7].

Although GPS receivers (trackers) can be used to recover rustled cattle and identify cattle that encroached into farmlands, yet existing trackers are energy deficient in long-term monitoring of livestock [10]. They require enormous energy for computing and transmitting geo-location data through cellular transceivers to remote servers. A recent field-test conducted on 5 trackers, configured to transmit their geo-location coordinates every 3 minutes discovered that the batteries in the trackers lasted 10 hours on average. This would imply that the final geolocation of the cattle is unknown if the cattle are stolen after the 10th hour.

Furthermore, researchers often deploy GPS trackers along with diverse sensors to study livestock movement, grazing pattern, health and location [8][9][15][24][25][26]. While concerted attempts have been made to reduce the financial cost of trackers [24][25], not a single research (in reviewed literature) was conducted to reduce the size of trackers for concealment on livestock. An obvious reason for a lack of interest in reducing the size of trackers for concealment on livestock is due to the absence of rustlers in the countries where researchers conduct livestock tracking. Thus current GPS wearable for livestock tracking

[10][27][28] are too large, they are visible and hence removable by rustlers. They are not ideal for the current research proposal. Portable tracking tags that can be attached to the ears of cattle exists [30], unfortunately, these tags can only work in close proximity to farm settlement network [30], moving the cattle away from the settlement automatically disconnects tracking activity.

Therefore this proposal addresses both research limitations. The size of the GPS receivers would be reduced to concealable size through 7 or 5 nanometers (nm) fabrication process, while low power ZigBee module will be added and energy-efficient algorithms would be developed and implemented to provide sustainable power to the tracking device for at least 2 years without recharging. Finally, the research proposal would set up virtual fences around areas restricted to cattle using geo-fencing application which triggers an alarm when approached.

#### 1.4 Conceptual Framework of the Study

Gordon Moore forecasted the annual doubling of electronic components that can fit on a single quarter-square-inch semiconductor (1.6129 square centimeters). His prediction is known as Moore's law [29]. The ability to double electronic components on a tiny piece of silicon wafer every year is the forerunner of device System-on-Chip (SoC) and System-in-Package (SiP) miniaturization processes. Major improvement in miniaturization of GPS tracking components has created smaller and more powerful devices. For example, most trackers use normal SIM card measuring 25x15x0.76mm, however, due to miniaturization, modern eSIM measure a paltry 2.5x2.3x0.2mm (see Figure 1) [33]. Therefore, trackers designed with eSIMs are smaller than their nano SIM counterpart.



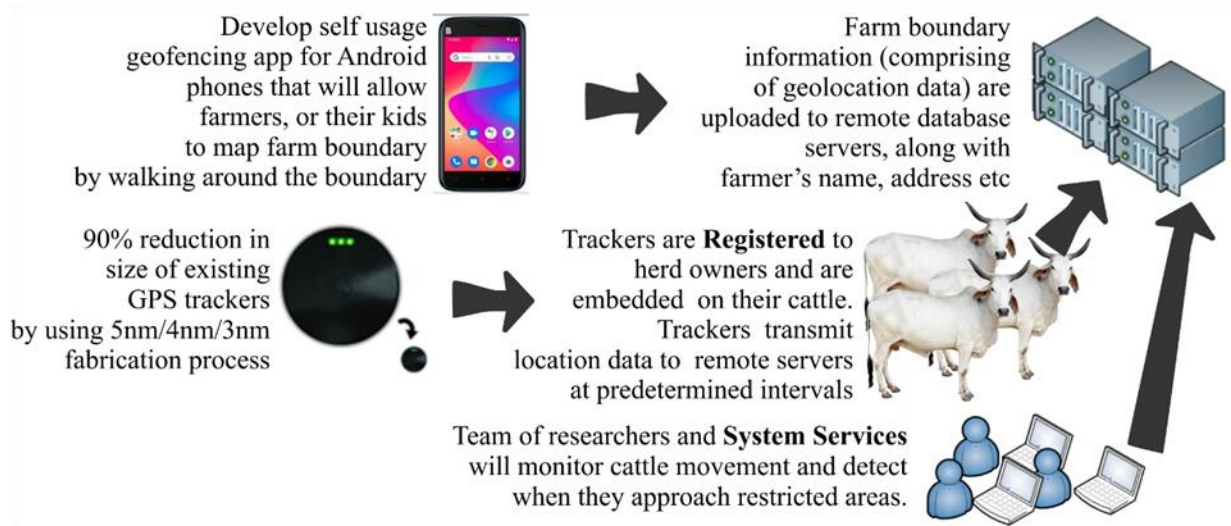
Figure 1: Showing the size of eSIM (2.5 x 2.3 x 0.2mm) [31]

Miniaturized trackers are currently available as sports wearable. These tracking devices are worn by athletes. Wearable trackers monitor movement of an athlete during sports [16][17]. Sports wearable come in different measurements. Dimensions for Samsung Galaxy Watch are 1.65 inches (41.9 mm) by 1.8 inches (45.7 mm) [18][19]. Huawei Watch are: 1.65 inches (42 mm) by 1.65 inches (42 mm) [20], and Huawei Band Pro: 1.77 inches (45 mm) x .75 inches (19 mm) [21]. Although wearables are smaller than smart phones, yet they are able to replicate all features of a smart phone on the wrist of the wearer. Since smart phones are miniaturized to fit on a wrist, it is empirically possible to scale down existing trackers for easy concealment by adopting wearable's SoC miniaturization technology.

From the foregoing, the key to the fabrication of concealable livestock trackers commences with the identification of ultra-small fabrication process. Existing ultra-small chip fabrication processes are 7nm, 5nm and 4nm fabrication process [32][33][34][35] [36], however 3nm fabrication process is expected to go mainstream by 2023 [37]. Samsung Exynos 2200 processor is fabricated base on the 4nm process node using SoC [36]. A major problem facing sports wearable is energy conservation, a fully charged wearable that is in fairly constant usage will last less than 24 hours before requiring a recharge [10][23]. On the issue of energy conservation, [44] has demonstrated how predictive sleep mode at the medium access control (MAC) layer can extend battery lifespan of ZigBee e-health devices by several years. Predictive sleep along with ZigBee module could be applied in the proposed tracker implementation

Most researchers conduct geo-fencing research on livestock to know when livestock enter or leave an area (for example watering hole, stream or farm boundary) [27][28]. These researchers are not interested in conducting geo-fencing studies that will prevent encroachment, because most farms have electric wires or other forms of fencing around their boundaries. Therefore geo-fencing algorithm that prevents farmland encroachment would be deployed.

In conclusion, the general overview of our project's conceptual framework is succinctly captured by Figure 2 below. The figure captures using mobile phone to create a virtual fence around farmlands. Geo-fence coordinates will be captured and transmitted to our remote servers in real-time. The presence of the farmland geo-location coordinates on the server will allow our proposed system to trigger an alarm as soon as the cattle approach the farmland.



*Figure 2: Showing concise project framework*

## 1.5 Research Outputs and Outcomes

### Research Outputs

- i. Successful miniaturization of energy-efficient trackers from 4.5x4.5cm to 0.45x0.45cm for concealment on livestock.
- ii. Successful design and deployment of geo-fencing software on Android smartphones. The software will allow farmers or surveyors to map every farm in the nation.
- iii. Successful design and deployment of database that will contain information on every farm, farmer, cattle, herder and trackers. This database will provide detailed information on farm and herd owners

### Research Outcomes

- i. Real-time and historical records of cattle movements will assist law enforcement agents to track rustled cattle or arrest herders who lead their cattle into farms.
- ii. Through registration of herders/farmers, the database of cattle owners/farmers will enable the system to know whom to call or send SMS in the event of imminent rustling or ongoing farmland encroachment.
- iii. Our trackers can be extended to locate kidnapped victims who concealed the miniaturize tracker on their clothes or body.
- iv. Also, rogue or compromised military or law enforcement agents who rent their weapons to bandits will be exposed because the embedded tracker will identify the location of such weapons.



## **1.6 Project Impact**

The successful implementation of this project will produce the following socio-economic impact on our nation:

- i. It will lead to the cessation of hostilities between farmers and herders. Because the ability to quickly locate and restore rustled cattle, as well as locate and collect restitution from herders who encroach into farmlands and damage farm produce will dissuade farmers and herders from avenging themselves.
- ii. When fully developed at the miniaturized state, this device can be produced in commercial quantity to create jobs through sales and installations of the trackers on humans, pets and assets (such as vehicles, cargo and family members).
- iii. The national database of farmers and their farmlands will enable state and federal governments to know total acreage committed to farming nationally and per state, and to formulate policies that will boost agriculture nationally.
- iv. The national database of herders and their cattle will enable state and federal governments to know the total number of cattle within the nation and in each state. This knowledge will assist policy makers to formulate the right policies.

## **2.0 RESEARCH DETAILS**

### **2.1 Literature Review**

Global research in livestock tracking adopted different tracking methods to track livestock movement, health, location and grazing pattern [8][9][15][24][25][26][27][28][30]. For example, [24] research work adopted GPS receivers embedded in collars and attached around the neck of cattle, [25] adopted tracking tags attached to cattle ears, [38] used Radio frequency identity (RFID) tags attached to cattle ears, [27][29] employed the use of trackers in form of wearables and so on. These traditional livestock monitoring GPS receivers (trackers) were large in size and cannot be concealed. This made them not applicable for anti-rustling applications.

Although, there is not a single research accessed in literature conducted to reduce the size of trackers for concealment on livestock due to the particularity of its application to certain countries or regions, [32][33][34][35] have shown that semiconductor components can be reduced to the levels of 5nm, 4nm, and 3nm through nanometer fabrication processes. Manufacturers implement device's size reduction by adopting SoC, SiP, double sided or

multilayer printed circuit board (PCB) process[39][40][41][42] ][43]. The SoC process enabled manufacturers to place a complete system (memory, processor, eSIM, GPS, and ZigBee) on a single die (side by side), while SiP enable manufacturers to stack different printed die (memory, processor, eSIM, GPS, and ZigBee) on top of each other. Also, double sided PCB allow manufacturers to cram multiple SoC or SiP chips on both sides of a PCB, while multilayer PCB allow manufacturers to cram multiple SoC or SiP chips on multiple layers of PCBs. However, double layers PCB are cheaper and easier to work with [41. One or more of these processes would be used in this research proposal.

Although device miniaturization reduces energy consumption in GPS enabled devices, however, the energy conserved is insufficient, the GPS enabled device requires recharge after 24 hours [23], or 10 hours [10]. For examples, GPS receivers operate in two power modes, these are: listening/tracking mode and receiving/acquisition mode. The maximum power consumed while in listening/tracking mode is 35.45mA (milliamps) while receiving/acquisition mode consumes 40.74mA [45]. On the other hand, LTE or 4G cellular transceivers dissipate 59mA to register with a network provider and 815mA to transmit data. A comparative analysis of energy dissipation between GPS receiver and LTE transceivers reveals that the LTE transceivers consumes more energy compared to GPS receiver [46]. Literature has presented works on cooperative transmission and predictive sleep mode using Zigbee (or other devices) as a means of energy conservation but no literature was accessed on their applications to livestock tracking system [44][47][48]. Consequently, algorithms to minimize energy usage of LTE transceivers in order to extend the battery-life of the proposed trackers will be presented. Similarly the scope of geo-fencing research work is minimal [27][28].

## **Related Work**

Several research works have been conducted in livestock monitoring and energy efficiency. Thus this research proposal carefully reviewed and evaluated related literatures that were written within the last five years. Evaluated literature dealing with livestock tracking and energy efficiency were carefully examined to identify individual limitations. Relevant papers have been tabulated for easier understanding and presentation in Table I.

Table I: Summary of Related Work

S/N	YEAR	AUTHORS	TITLE	SCOPE	PROS	LIMITATIONS
1	2020	Usman I.H., Arokhamoni A. I., Yusuf M. A. & Jumba A.M.Y.	Design, Fabrication and Deployment of Anti-Rustling Tracking System	Livestock monitoring using GPS and 4G LTE	Real-time monitoring of livestock movement	Trackers were too large; battery depletes after 10 hours; and no support for geo-fencing.
2	2018	Agetegba, M. Y.	A Predictive Media Access Control Protocol for Energy Efficient Wireless Sensor Network for E-health Applications	Energy efficiency of ZigBee devices	Extended ZigBee energy savings features using predictive sleep	Limited to mathematical equations and simulations
3	2020	Felix Adrion, Markus Keller, Giulia Bianca Bozzolini and Christina Umstatter	Setup, test and validation of a UHF RFID system for monitoring feeding behaviour of dairy cows	Monitoring livestock feeding habits using UHF RFID	Identified livestock that feed more and those who feed less	Research is limited to enclosure. RFID tags in ears are easily identified and can be remove. Limited to feeding habits.
4	2020	Afrianto, Irawan, Sri Wahjuni, and Taufik Djatna	Model of Ubiquitous Precision Livestock System 4.0: A Technological Review	Livestock and grassland monitoring	Monitor's grassland and livestock location using GPS, geofences and drones	Ignores power limitation of battery operated devices. Geofences are limited to entry and exit, not actively preventing entries
5	2020	Akbar, Muhammad Osama, et al	IoT for Development of Smart Dairy Farming	Livestock monitoring, behavioral monitoring and feeding improvement	Livestock location, physical posture, geofencing and temperature monitoring	Large observable trackers. No effort to conserve energy on battery operated trackers
6	2021	Bailey, Derek W., et al.	Opportunities to apply precision livestock	Livestock and pasture monitoring	Monitor's livestock position, pasture,	Trackers are visible, no consideration for energy

			management on rangelands		water source, geofencing and health	efficiency. Geofence is limited to animal entry and exit of pasture and water sources
7	2019	Karl, Jason W., and James E. Sprinkle	Low-cost livestock global positioning system collar from commercial off-the-shelf parts	Manufactured livestock tracking, implemented energy conservation	Livestock monitoring using trackers, extended battery lifespan to 20 days	Trackers store geolocation data on memory cards instead of transmitting to remote servers. Trackers too large
8	2020	Foley, Conrad J., and Claudio	Open-source, low-cost modular GPS collars for monitoring and tracking wildlife	Wildlife monitoring using manufactured GPS	Manufactured GPS device to track wildlife	Trackers too large, no effort to conserve energy
9	2021	Waqar, Adnan, et al	Analysis of GPS and UWB positioning system for athlete tracking	Athlete movement tracking	Uses wearable devices that tracking location via Indoor Positioning System tracking	IPS is expensive compared to GPS, IPS is limited to a location. No effort to conserve energy
10	2021	Ilyas, Qazi Mudassar, and Muneer Ahmad.	Smart Farming: An Enhanced Pursuit of Sustainable Remote Livestock Tracking and Geofencing Using IoT and GPRS	Livestock tracking and attempts at energy conservation	Livestock tracking using GPS and ultrasonic sensors. Attempts at minimizing energy by activating trackers when animal leaves the geofence	Research proposal, no actual deployment.
11	2019	Abdullahi, U. S., et al	Exploiting IoT and LoRaWAN technologies for effective livestock monitoring in Nigeria.	Livestock tracking	Livestock tracking within a ranch using LoRa and Internet of Things (IoT)	Fixed location, cattle will be lost if they wander out of LoRa network range. No attempt to conserve energy

12	2020	Xu, Beibei, et al	Livestock classification and counting in quadcopter aerial images using Mask R-CNN	Livestock monitoring	Monitors livestock using computer drones and computer vision to count livestock and group by species .	Cannot track stolen animals can only count available animals
13	2020	Ngo, Ha Quang Thinh, Thanh Phuong Nguyen, and Hung Nguyen	Research on a low-cost, open-source, and remote monitoring data collector to predict livestock's habits based on location and auditory information: a case study from Vietnam	Livestock monitoring	Location, feeding and temperature tracking	Collars are large and consumes energy
14	2022	Nyamuryekun g'e, S., et al	Performance of Lora-WAN Sensors for Precision Livestock Tracking and Biosensing Applications.	Livestock monitoring	Monitor's livestock using LoRa network and LoRa GPS device	Network range limited due to LoRa adoption. No attempt to make trackers concealable and energy efficient.
15	2021	Tedeschi, Luis O., Paul L. Greenwood, and Ilan Halachmi	Advancements in sensor technology and decision support intelligent tools to assist smart livestock farming	Livestock monitoring	General overview of smart farming and livestock management	No discussion on GPS miniaturization or energy conservation

### *Summary of Related Work*

A summary of the papers reviewed in Table I above surmises two key limitations in livestock monitoring using GPS receivers, namely large size and high energy depletion rate. Trackers based on LoRa networks are limited in range, thus cattle herds can be rustled outside the

range of the LoRa network. Similarly, existing GPS receivers are large and energy intensive, lasting only 10 hours when using LTE to transmit geolocation coordinates to remote servers every 3 minutes. However, a research that eliminated 4G LTE transmission in GPS receivers was able to extend battery energy by 20 days before requiring a recharge. The research saved location data on SD Cards. This approach is not useful in real-time cattle tracking scenario. Livestock monitoring using embedded RFID tags and tag readers are expensive to deploy nationwide. RFID tags are only useful when tags readers are discreetly deployed across the nation. A major limitation of RFID tags is the unreachability of cattle herds roaming in areas without tag readers.

## **2.2 Research Methodology**

The proposed research adopts three-pronged methods to achieve the fabrication of energy efficient GPS trackers and to design, develop and deploy geo-fencing application for Android smartphones. The three-pronged methods are: Data collection, Data Analysis, System Development and Implementation, and System Evaluation.

### Data Collection and Analysis

The proposed research commences with three (3) concurrent data collection drive. The first data collection will target 3 (three) dedicate component manufacturers of eSIMs, Processors, LTE Transceivers, GPS receivers, and Memory Units in the US, China, Taiwan, and South Korea. The importance of this data collection is to analyze the different sizes of individual chips from different manufacturers.

The second concurrent data collection drive target 3 renowned and 2 not so renown SoC and SiP semiconductor manufacturers in USA, China, Taiwan and South Korea. Data collected will identify manufacturers who can produce custom SoC or SiP chips using 7nm/5nm fabrication process. This important step will enable this research proposal to observe variations between manufacturers and evaluate the most promising manufacturer whose fabrication process will achieve the research's miniaturization target and quality. While the first two data collection drive dealt with hardware, the third data collection will target four (4) database software development companies around the world. Data collected will help identify the best database that is optimized for hosting continuous data from diverse trackers.

## System Development and Implementation

The proposed system development processes are subdivided into three, namely hardware design, mobile application development, web application development and energy conservation.

### *A. Hardware Design (Miniaturization)*

The design goal of this research proposal is to produce a SoC/SiP GPS receiver measuring 0.45 x 0.45 cm (4.5 x 4.5mm) using either 7nm or 5nm manufacturing process.

Both SoC and SiP device design process combines different standalone integrated circuits (ICs) into a single chip. For example, various chips like 4G LTE Advanced transceiver, ZigBee transceiver, GPS receiver, Sensors, Memory units and CPU are combined and printed on a single die, by laying them side by side (SoC) or by stacking them one upon another (SiP).

The research proposal adopts either 7nm or 5nm fabrication process because TSMC's N5 (5nm) technology N5 technology provides about 20% faster speed than N7 technology or about 40% power reduction. Moreover, TSMC's 5nm fabrication process can pack over 170 million transistors per square millimeter (MTr/mm<sup>2</sup>), while 7nm can pack about 151 million per square millimeter. This implies the proposed 5nm fabrication process can pack over 760 million transistors on the proposed 4.5 x 4.5mm miniaturized target. 5nm fabrication will greatly improve the proposed GPS tracker with more memory, more processing power and less power consumption. While the project goal is 4.5x4.5mm miniaturization, it is empirically possible to achieve a smaller size due to rapid improvement in the semiconductor fabrication industry.

The block diagram of the GPS receiver in Figure 3 represents the schematic diagram of a previous tracker deployed by the researchers [10]. While Figure 4 represents the proposed block diagram of the current research miniaturization target. The main components of the proposed GPS receiver are briefly explained below:

4G/LTE Advanced: The 4G/LTE Advanced transceiver is responsible for transmitting computed GPS geolocation coordinates to remote servers via GSM cellular network. It can switch between 2G/3G/4G networks depending on which is available.

ZigBee/IEEE 802.15.4: It uses the 2.4 GHz frequency band, with a range of 70m indoors and 400m outdoors. ZigBee's low latency and low duty cycle extends battery life to 7 years.

eSIM: The eSIM module stores the subscriber identification number assign to the GPS device by the network provider. It can store multiple numbers from different providers..

CPU: The central processing unit is responsible for complex computations required by the GPS receiver, it will contain two (2) or more interrupts that will determine which connectivity should take precedence.

Memory: The memory module plays an important role in the proposed GPS receiver. Aside from storing programs and corresponding data, it equally stores the computed geolocation of all cattle, if the current GPS receiver is selected to act as the PAN coordinator.

Sensor Core: The sensor core contains all sensors necessary for livestock tracking. Sensors that can be replicated using software may not be included in the proposed GPS receiver. For example, functions such as accelerometer can be simulated using software.

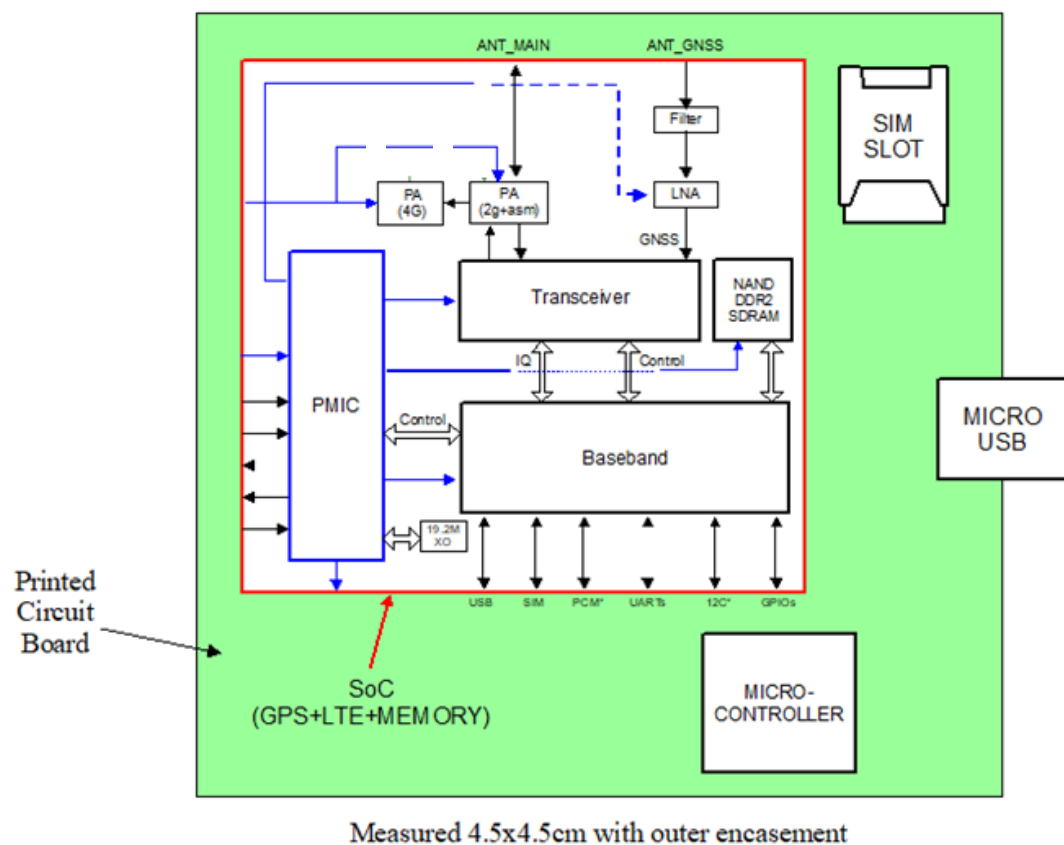


Figure 3: Block Diagram of Previous GPS device from Previous Research



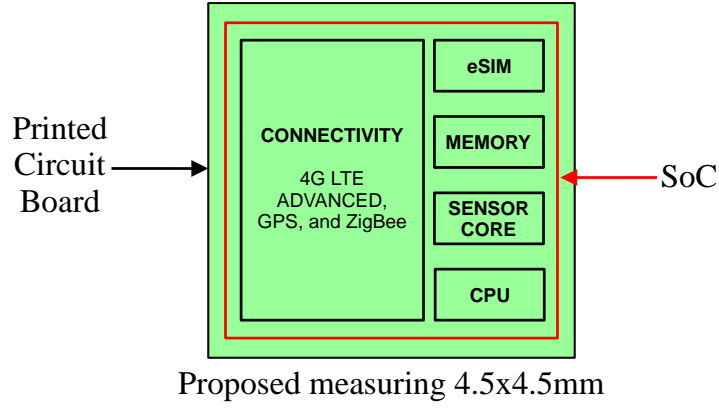


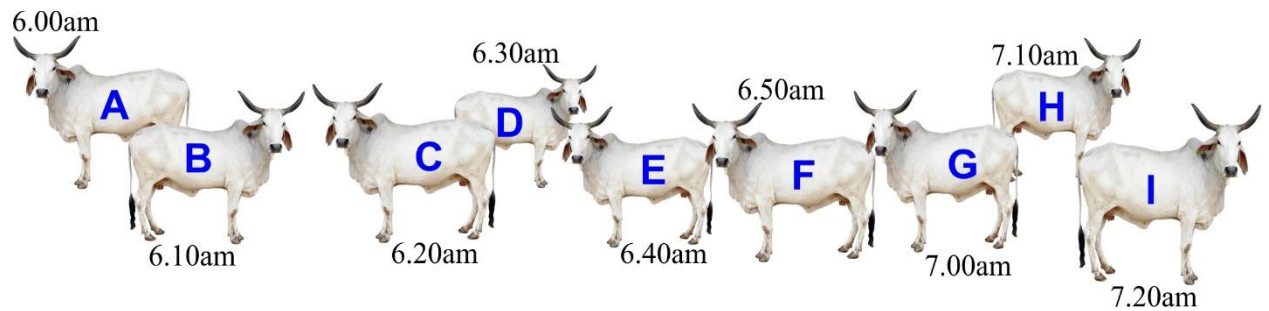
Figure 4: Block Diagram of proposed GPS device

### B. Energy Conservation

The research proposal adopts the universal formula  $E = Pt$  (*energy = power multiplied by time*) which posits that the energy consumed by a transceiver is determined by transmission or reception voltage (*power*) multiplied by transmission or reception duration (*time*). Therefore, the key to lowering energy consumption in battery operated communication devices is by intelligently limiting transceiver's usage.

Since 4G LTE Advance transceivers consumes more energy compared to ZigBee transceivers, the research proposal proposes using ZigBee to collate geolocation data from every GPS node on the network. Collated data are forwarded to the current PAN coordinator (PANC) for transmission via 4G LTE transceiver. Modifying GPS receivers to collate geolocation data via ZigBee WSN extends the lifespan of the battery by limiting usage of 4G LTE transceivers. This is achieved by adding predictive algorithm that determines GPS device sleep and wake intervals. Each GPS device will be able to receive, compute and transmit geolocation data at re-programmable intervals. This approach eliminates channel contention, it equally eliminates network overheads since messages are forwarded to the current PANC and not bounced around the WSN repeatedly.

Predictive sleep duration for each GPS node is stored in a re-programmable lookup table. Each node will have its own wake up time, therefore each node will be able to transmit data at different times, eliminating the need for low-power-listening, long or short preamble and RTS/CTS (Request To send/Clear To Send). Predictive sleep and messaging (P\_SLEEP) assigns the responsibility of transmitting geolocation data to one PANC during each transmission cycle [44]. The art of cooperative transmission is captured in Figure 4 below:



*Figure 6: Proposed 4G LTE Transceiver Usage*

Bull A transmits on behalf of all cattle at 6:00am, bull B follows at 6:10am, this continues until 7:20am when bull I transmits on behalf of the entire herd. Thereafter, bull A automatically resumes the duty of PANC and transmits on behalf of the herd at 7:30am. An important feature of predictive sleep and messaging from the example above is that the 4G LTE transceiver of each bull is active once in 1 hour 20 minutes! This implies the transceiver has ample time to sleep and conserve energy, thus the more the cattle herd the more energy the device conserves. The algorithm below represents two processes: firstly, how PANC are assigned, secondly how predictive sleep conserve energy.

```

BEGIN(Startup or Wakeup)
    Set TotalNodes to 0
    Set DeviceID to 0
    Set PANC to 0
    Set NextPANC to 0

    Get Stored_Device_ID FROM Memory
    Set DeviceID to Stored_Device_ID
    Set Geolocation to Computed_Geolocation

    IF Wakeup
        Get ID_of_PANC FROM Memory
        Set PANC to ID_of_PANC

        Switch Radio from SLEEP MODE to LISTEN MODE

        IF PANC = DeviceID THEN
            Compute Next Wakeup Time

            Advertize Self AS PANC
            Set NextPANC to PANC + 1

            Wait for incoming messages

            IF message Received THEN
                Get ID of Sender
                Store ID of Sender

```

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        Increment TotalNodes by 1
        Add Sender geolocation to Geolocation
    END IF

    IF No More Messages THEN
        Transmit Geolocation via 4G LTE

        IF NextPANC > TotalNodes THEN
            NextPANC = 1
        END IF

        IF NextPANC exists in Sender IDs THEN
            Advertize NextPANC ID as PANC
            Advertize Next Wakeup Time
        ELSE
            Set NextPANC = Sender ID > PANC
            Advertize NextPANC ID as PANC
            Advertize Next Wakeup Time
        END IF

        Switch Radio to SLEEP MODE
    END IF
ELSE
    Send Computed GPS Geolocation to PANC
    Wait for ID of Next PANC
    Wait for Next Wakeup Time
    Switch Radio to SLEEP MODE for x Minutes
END IF
ELSE
    Turn on Radio

    Wait for incoming messages

    IF message Received THEN
        Get ID of Sender
        Store ID of Sender
        Increment TotalNodes by 1
        Add Sender geolocation to Geolocation
    END IF

    IF No More Messages THEN
        Check All Sender IDs
        Set Device with the Lowest ID as PANC

        PANC advertizes itself

        Other non-PANC nodes:
        Send GPS Geolocation to PANC
        Wait for PANC to advertize:
        ID of Next PANC
    
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```

Next Wakeup Time
Switch Radio to SLEEP MODE for x Minutes
END
END IF
STOP

```

The algorithm above has two modes of operations, which is Startup mode (when devices are powered up for the first time) and Wakeup mode (when devices wake up from predictive sleep).

PANC selection during Wakeup is straightforward. The current PANC selects the next PANC by assigning the device with an ID that is higher than itself the role of the NextPANC. However, if the NextPANC value is greater than TotalNodes, then the next PANC will revert to the first PANC (A)

Energy saved by GPS nodes using predictive sleep can be computed and compared with nodes that transmit without predictive sleep, the values in Table II below will be utilized in the computation.

Table II: Energy dissipation values for different ZigBee [44]

Operation	Telos	Mica2	MicaZ
Minimum Voltage	1.8V	2.7V	2.7V
Mote Standby (RTC on)	5.1 $\mu$ A	19.0 $\mu$ A	27.0 $\mu$ A
MCU Idle (DCO on)	54.5 $\mu$ A	3.2 mA	3.2 mA
MCU Active	1.8 mA	8.0 mA	8.0 mA
MCU + Radio RX	21.8 mA	15.1 mA	23.3 mA
MCU + Radio TX (0dBm)	19.5 mA	25.4 mA	21.0 mA
MCU + Flash Read	4.1 mA	9.4 mA	9.4 mA
MCU + Flash Write	15.1 mA	21.6 mA	21.6 mA
MCU Wakeup	6 $\mu$ s	180 $\mu$ s	180 $\mu$ s
Radio Wakeup	580 $\mu$ s	1800 $\mu$ s	860 $\mu$ s

Using values in Table 2 above, the paper computed equations to determine predictive sleep and messaging energy conservation levels, using variables defined below:

$t_{SECONDS}$  = Total time in seconds

Energy = Power \* Time

Since  $P = IV$  = Current \* Voltage

Therefore:  $E=IVT$  = Current \* Voltage \* Time

$t_{SECONDS}$  = Total time in seconds

Micaz TX_ENERGY =	Current (in mA) consumed by MicaZ while transmitting multiply by the Voltage and Time (Since $E=PT$ and $P=IV$ , hence $E=IVT$ )
Micaz RX_ENERGY =	Current (in mA) consumed by MicaZ while receiving multiply by the Voltage and Time (Since $E=PT$ and $P=IV$ , hence $E=IVT$ )
N_NODES =	Number of nodes
TX FREQUENCY =	Rate of Transmission in seconds
RX FREQUENCY =	Rate of Reception in seconds
t <sub>1</sub> =	Total seconds spent transmitting data without P_SLEEP
t <sub>2</sub> =	Total seconds spent receiving data without P_SLEEP
t <sub>1_P_SLEEP</sub> =	Total seconds spent transmitting data with P_SLEEP
t <sub>2_P_SLEEP</sub> =	Total seconds spent receiving data with P_SLEEP
V <sub>POWER</sub> =	Micaz mote voltage

Therefore:

t <sub>SECONDS</sub> =	3600 seconds (1 hour)
Micaz TX_CURRENT =	21 mA
Micaz RX_CURRENT =	23.3 mA
V <sub>POWER</sub> =	2.7 V
N <sub>NODES</sub> =	8
TX FREQUENCY =	2 seconds
RX FREQUENCY =	3 seconds
t <sub>1</sub> =	$t_{SECONDS} \div TX\_FREQUENCY$
t <sub>2</sub> =	$t_{SECONDS} \div RX\_FREQUENCY$
t <sub>1_P_SLEEP</sub> =	$t_{SECONDS} \div N_{NODES} / 60$
t <sub>2_P_SLEEP</sub> =	$t_{SECONDS} \div N_{NODES} / 60$

The following equation calculates transmission energy consumed without predictive sleep and messaging:

$$\text{Energy}_{TX} = \text{Micaz}_{TX\_CURRENT} * V_{POWER} * t_1$$

$$\text{Energy}_{TX} = 56.7 * t_1 \text{ (mjoules)} \quad (1)$$

The next equation calculates energy consumed while receiving data without P\_SLEEP:

$$\begin{aligned} \text{Energy}_{RX} &= \text{Micaz}_{RX\_CURRENT} * V_{POWER} * t_2 \\ \text{Energy}_{RX} &= 62.91 * t_2 \text{ (mjoules)} \end{aligned} \quad (2)$$

The final set of equation calculates energy consumed while transmitting and receiving data with P\_SLEEP:

$$\begin{aligned} \text{Energy}_{TX} &= \text{Micaz}_{TX\_CURRENT} * V_{POWER} * t_{1\_P\_SLEEP} \\ \text{Energy}_{TX} &= 56.7 * t_{1\_P\_SLEEP} \text{ (mjoules)} \end{aligned} \quad (3)$$

$$\begin{aligned} \text{Energy}_{RX} &= \text{Micaz}_{RX\_CURRENT} * V_{POWER} * t_{2\_P\_SLEEP} \\ \text{Energy}_{RX} &= 62.91 * t_{2\_P\_SLEEP} \text{ (mjoules)} \end{aligned} \quad (4)$$

Results are show below in Joules (without P\_SLEEP):

$$\begin{aligned} \text{Energy}_{TX} &= 56.7 * t_1 \text{ (mjoules)} \\ \text{Energy}_{TX} &= 102060 * 0.001 \text{ (mjoules)} \\ \text{Energy}_{TX} &= 102.6 \text{ (joules)} \end{aligned} \quad (5)$$

$$\begin{aligned} \text{Energy}_{RX} &= 62.91 * t_2 \text{ (mjoules)} \\ \text{Energy}_{RX} &= 75492 * 0.001 \text{ (mjoules)} \\ \text{Energy}_{RX} &= 75.5 \text{ (joules)} \end{aligned} \quad (6)$$

Results are show below in Joules (with P\_SLEEP):

$$\begin{aligned} \text{Energy}_{TX} &= 56.7 * t_{1\_P\_SLEEP} \text{ (mjoules)} \\ \text{Energy}_{TX} &= 453.6 * 0.001 \text{ (mjoules)} \\ \text{Energy}_{TX} &= 0.45 \text{ (joules)} \end{aligned} \quad (7)$$

$$\begin{aligned} \text{Energy}_{RX} &= 62.91 * t_{2\_P\_SLEEP} \text{ (mjoules)} \\ \text{Energy}_{RX} &= 503.28 * 0.001 \text{ (mjoules)} \\ \text{Energy}_{RX} &= 0.50 \text{ (joules)} \end{aligned} \quad (8)$$

From the above calculations, P\_SLEEP dissipates the least energy since each node will be able to transmit and receive 8 times within an hour (every 8 seconds). Longer sleep duration translates to more power conservation. P\_SLEEP is designed to address the following:

- a. Eliminates low power listening in data gathering devices. Nodes only power up their radios to report collated records.
- b. Eliminates collision using predictive algorithm, since two nodes can't hog the communication channel at the same time.
- c. Eliminates overhearing and protocol overhead since every communication is between the reporting node and the PANC (other nodes route the data if the sender is far from PANC's range).
- d. Ensure nodes have guaranteed time slots to send messages.
- e. Eliminates idle node in medical data gathering devices.

### *C. Software Design: Geo-fencing*

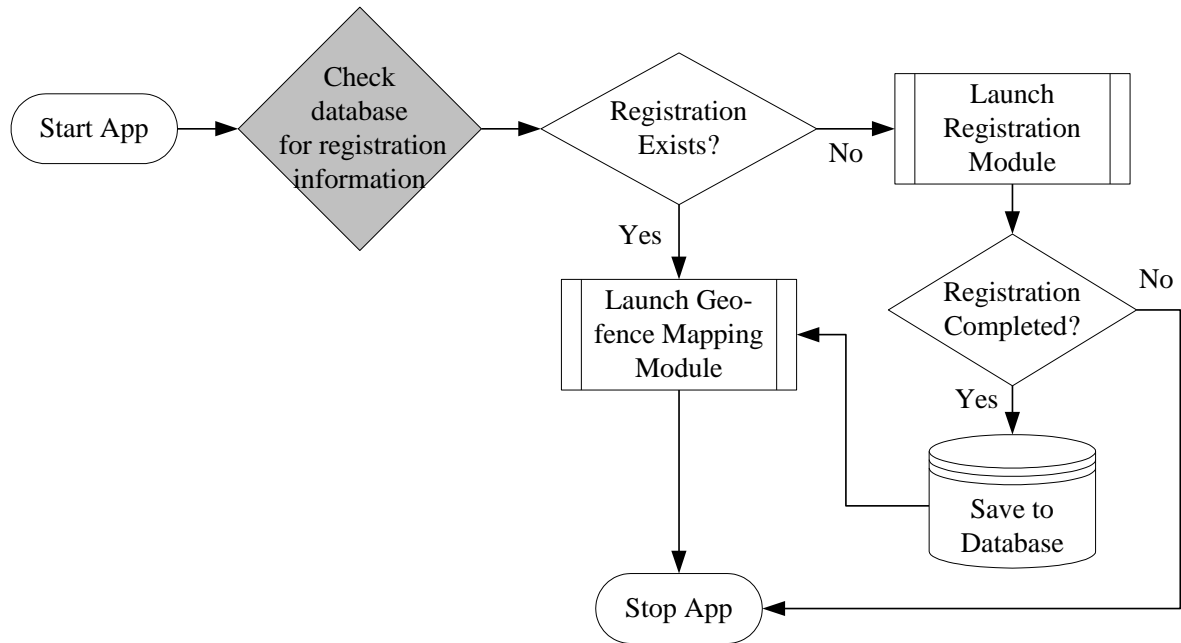
The proposed geo-fencing software will allow users (for example farmers) to map areas that are restricted to cattle. Users are able to map restricted boundaries by walking or driving around the restricted area with the software running on their mobile phones. The basic system requirements of the proposed Android based mobile application are listed in Table III below:

Table III: Geo-fencing Application System Requirements

ANDROID VERSION	GPS	SENSORS	INTERNET	REMARKS
Android 5.0 (Lollipop)	Yes	Accelerometer Gyroscope	Yes	Both accelerometer and gyroscope will provide altitude and directional information

Enumerated below are the various stages of the proposed system:

- i. Registration: First time users are required to register before they can use the software. Required registration information include Surname, Other Names, Gender, Date of Birth, Home Address, Mobile Phone No., NIN, Farm Location (State, LGA, Town) etc. Completed registration information will be transmitted to remote servers for storage. The flowchart in Figure 5 below captures the registration process.



*Figure 7: Proposed Registration Module for Geo-fence Application*

- ii. Boundary Mapping: Boundary mapping allow the farmer or user to create a geo-fence around restricted area by walking, riding or driving around the area. Users can Start, Pause, Resume, End or Cancel mapping at any point during geo-fence creation. The process is captured by the flowchart in Figure 6 below.



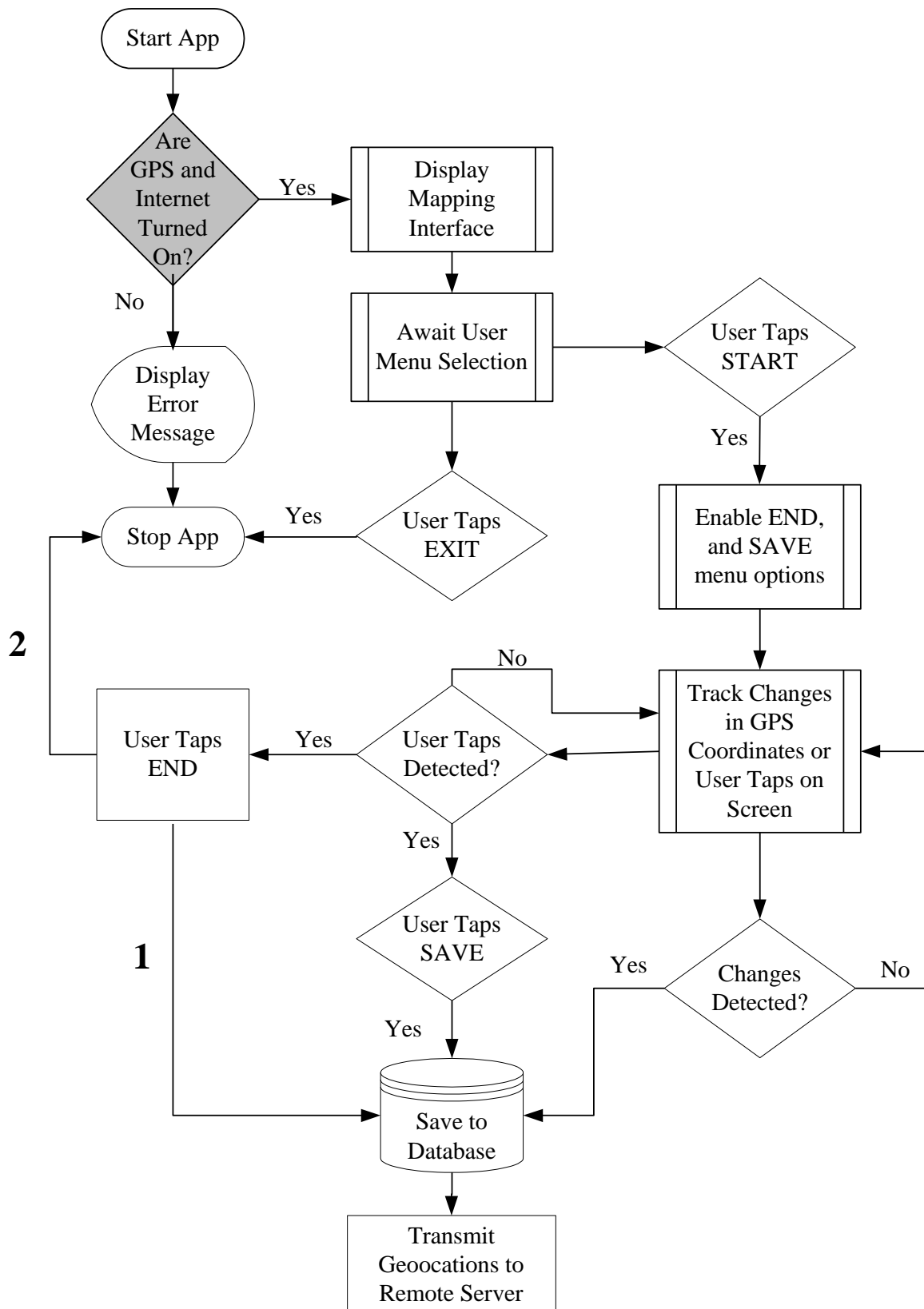


Figure 8: Proposed Geo-fence Creation Module

#### *D. Software Design: Web Application*

The proposed web application is central to the modus operandi of the proposed research. It combines 24/7 geo-fence and cattle location monitoring features. The basic system requirements of the proposed web application are listed in Table IV below:

Table IV: Web Application System Requirements

OPERATING SYSTEM	GPS	SENSORS	INTERNET	REMARKS
Any operating system that supports an Internet Browser.	No	No	Yes	The web application will run on Android, iOS and Windows and Chrome devices. As long as the device has a functional browser

Enumerated below are the various modules of the proposed system:

- i. Registration Modules: The proposed registration modules are central to the system's operations. The following registration modules will feature in the proposed system:

*Users Registration Module*: This module will allow the system administrator to register additional users and assign roles to each user. Proposed roles are listed in Table V below:

Table V: User Groups and Roles in the Proposed System

USER GROUP	ROLES
ADMIN	Can interact with the entire system
OPERATOR	24/7 monitoring of cattle movement nationwide. These set of users will work in shifts and monitor cattle by observing their movement. Their operation will be similar to air traffic controllers. The proposed group will call herd owners if their cattle are approaching a restricted area
FRONT DESK	Register Farmers and Herders. Will update information on herders and farmer's information when needed. This group can receive calls from herd owners who wish to report stolen cow, bull or an entire herd.
TECHNICAL	Register and assign trackers to cattle. Create geo-fences on behalf of farmers or herders
SECURITY	This group monitors the current location of stolen or rustled cattle only. They work with law enforcement to recover rustled cattle.

*Herders Registration Module*: This module will allow users to register cattle owners nationwide. Required registration information include Surname, Other Names, Gender, Date of Birth, Home Address, Mobile Phone No., NIN, Grazing Mode (ranch, RUGA, open grazing/free range) etc.

*Farmers Registration Module:* Although the proposed geo-fencing application will transmit required information on farmers and their farm locations, nonetheless, the researchers are aware that not every farmer will be able to afford a mobile phone, nor afford the cost of hiring a tech savvy user to help with the mapping. This module will allow users to register farmers on the system.

*Trackers Registration Module:* This module will handle registration of all trackers, using their serial numbers. This module will automatically register a million trackers by prompting the user to specify the first serial number, the system will then automatically increment the serial number until it reaches 1 million.

- ii. Trackers Assignment Module: The proposed tracker assignment module will allow users to assign trackers to cattle. The proposed module is fully automated, a hundred (100) trackers can be assigned to 100 cattle herd by simply selecting the herd owner and then typing the first serial number, then the number of cattle to assign serial numbers to, the system automates the assignment and saves the result to a database:
- iii. Live Tracking Module: The proposed live tracking module will enable users in Admin and Operator groups to monitor general cattle movement nationwide. However, users in Security group will be restricted to monitoring rustle cattle or asset only.
- iv. Playback Module: The proposed Playback module will enable users in Admin group to view historical records of cattle movement nationwide. However, users in Security group will be restricted to viewing historical records of rustle cattle or asset only.
- v. Geo-fence Module: The proposed geo-fence module will enable users in Admin and Technical groups to create geo-fences around farms on behalf of farmers. Herd owners may also request the creation of geo-fences and around one or more states, this will alert the herd owner if any of his/her herd leaves the geo-fenced area. This module works by allowing users to draw a circle or rectangle or square around the target area in mapping software like Google map. The act of drawing these shapes around the map will automatically capture the longitudes and latitudes (geolocation coordinates) of the area. This will be saved automatically to the proposed database.

### *E. Software Design: Trackers API Development*

The proposed web application programming interface (API) development will enable controlled interaction with the proposed trackers. Enumerated below in Table VI are some APIs that will facilitate controlled configuration of trackers.

Table VI: Trackers APIs in the Proposed System

API	VALUE	DESCRIPTION
GpsSleepInterval	0 = 30 seconds, 1= 3 minutes, 2 = 10 minutes	Set the sleep interval of GPS receiver, that's how often it remains in low-power sleep mode before powering up to full power and receive coordinates from GPS satellites in space.
ZigbeeSleepInterval	0 = 30 seconds, 1= 3 minutes, 2 = 10 minutes	Set the sleep interval of ZigBee device, that's how often it remains in low-power sleep mode before powering up to full power to form WSN and transmit geolocation coordinates.
PredictiveMode	0 = ON. 1 = OFF	Predictive mode determines if all ZigBee devices transmits at the same time (leading to channel contention) or at predetermine times

Programming the values above is as easy as setting various predefined registers in erasable programmable read-only memory (EPROM) of the proposed GPS device to the desired values.

### Evaluation of the Propose System

The proposed system will be evaluated based on performance, device concealability and energy efficiency. Performance will be evaluated based on the accuracy of transmitted cattle location vis-a-vis actual location. GPS receivers that use the L5 band can have much higher accuracy, pinpointing to within 30 centimeters or 11.8 inches of the actual location.

Device concealability will be evaluated based on the ability to conceal the tracker without degrading its' performance, nor affecting the health or operation of the cattle or asset.

Finally, energy efficiency will be measured based on the longevity of the battery. A satisfactory target is two (2) years without recharge.

## **2.3 Project Activities and Outputs**

### Activities

- a) Data collection from 8 electronic component and SoC/SiP manufacturers worldwide.
- b) Data collection from 4 database management system developing companies worldwide.
- c) Analysis of obtained data
- d) GPS's SoC or SiP design based on obtained data
- e) Database design for web application based on obtained data
- f) Concurrent web and mobile application development
- g) Tracker deployment on test cattle
- h) Testing of the implemented system
- i) Documentation

### Outputs

- a) Meaningful feedback and relevant data for the research
- b) Detail result on how the proposed system should work
- c) Working model and framework of the proposed system
- d) Manufacturing of the Prototype of the proposed system
- e) Testing the tracking functionalities of the Prototype Tracker

## **2.4 Timeframe**

The estimated project timeframe is twenty-four (24) months. The duration can be attributed to the project activities and the gradual easing of the global shortage of integrated circuits as a result of manufacturers shutting down to mitigate COVID-19. Project time frame is represented in the Gantt chart, see Table VII.

Table VII: Trackers APIs in the Proposed System

GANTT CHART																										
TASKS	2023													2024												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D		
Data Collection																										
Data Analysis																										
Hardware Design																										
Database Design																										
Software Design																										
Tracker Deployment																										
Testing																										
Documentation																										

## 2.5 Key Performance Indicators

<b>Activities</b>		<b>Ready By</b>
(a)	Data Collection	Feb. 2023
(b)	Publication of 2 Peer-Reviewed Papers in International Journals <ul style="list-style-type: none"> <li>i. Novel Energy Conservation in a Network of GPS Receivers</li> <li>ii. Long-term Livestock Monitoring Using Miniaturized Trackers</li> </ul>	Aug. 2023 Aug. 2024
(c)	Data Analysis	Apr. 2023
(d)	Hardware Design	May. 2023
(e)	Database Design	May. 2023
(f)	Software Design	Nov. 2023
(g)	Tracker Deployment	May. 2024
(h)	Testing	Dec. 2024
(i)	Documentation and user manuals	Dec. 2024

## 2.6 Monitoring and Evaluation Mechanism

Monitoring and Evaluation Mechanism of proposed project includes the following

- i. Two (2) peer-reviewed papers will be produced and sent for review and publication in reputable international journals in a bid to bridge existing/identified research gaps.

- ii. The proposed hardware and software prototypes will be compared with existing solutions to ensure novelty and innovative improvement over existing schemes.
- iii. Experts will be able to interact with the system and will publish their findings.
- iv. A Joint account will be open with three (3) signatories to ensure financial monitoring and control and funds will be accessed according to current project activities

## 2.7 Dissemination Strategies

The immense benefits expected from the project will be disseminated to key stakeholders through paper presentation, workshops, local conferences, seminars, technical report and publication in reputable foreign journals.

## 3.0 The Research Team

### 3.1 Composition of Research Team

S/N	Names	Rank	Highest Qualification	Area of Specialization
1	Engr. Usman Isa Hassan	Principal Lecturer	MSc.	Electronics / Communication
2	Mr. Arthur Ibukunoluwa Arokhamoni	Chief Solution Architech	Others	Software Development and Hardware Integrator
3	Dr. Muhammad Yusuf Agetegba	Head Business Process Automation	PhD.	Wireless Sensor Networks
4	Dr. Mohammed Abdullahi	Chief Lecturer	PhD.	Ruminant Production and Management
5	Engr. Fatima Muhammad	Technologists	BSc.	Electrical / Electronic
6	Engr. Aliyu Abubakar Garba	Others	BSc	Electrical / Electronic
7	Surv. Shehu Mohammed Kardam	Chief Lecturer	MSc.	Geographic Information System Analyst
8	Dr. Damina Mohammed Sadiq	Others	Others	Molecular Epidemiology
9	Dr. Hassan Buhari Mamman	Senior Lecturer	PhD	Bioelectronics and Embedded System

### **3.2 Brief Profile of the Research Team**

ENGR. USMAN ISA HASSAN is currently Principal Lecturer at the Federal Polytechnic Bauchi and a PhD student (awaiting defense) in Abubakar Tafawa Balewa University Bauchi in the field of electronics (communication). He is a seasoned industrialist who worked for 10 years in the defunct Nigeria Mobile Communication Limited (MTEL) and presently lecturing for over 10 years. A dependable team player in designing systems/algorithms with the required problem oriented parameters to meet current challenges in electronics and communication spaces. He rose to the position of Head of Network Monitoring and Optimization Unit in MTEL and currently the chairman of Electrical/Electronic Department Research Committee. He published peer-reviewed journals and conferences of 20 articles.

ARTHUR IBUKUNOLUWA AROKHAMONI is currently the Chief Solution Architect of ArtMannTech Solutions. He oversees the development of cutting-edge solutions for business and academic institutions. He has consulted for Anchor University Ayobo, Lagos, Deeper Life High Schools (nationwide), The Institute of Professional Studies (IPS), Ilaro, Albesta Academy, Lekki and The Federal Polytechnic, Ilaro. His business software consultancy covers stock-broking, accounting and inventory management, integrating his accounting and inventory solution with Benin Republic automated tax remitting system. He is currently working on a project that will allow Nigerian youths to learn Python programming in Hausa, Igbo, Pidgin-English and Yoruba. The project is codenamed 9ja-Reboot and was demonstrated at the 2022 Abuja NSE Conference – along with the accompanying paper. He authored a book on computer science and has provided computer simulations services to several peer-reviewed papers, one of which won a digital award.

ENGR. ALIYU ABUBAKAR GARBA is currently a Lecturer I at the Federal Polytechnic Bauchi and a M.Sc. student in Abubakar Tafawa Balewa University Bauchi in the field of communication engineering. He carried out experiments and supervises student projects.

ENGR. FATIMA MUHAMMAD is currently a Principal Technologist at the Federal Polytechnic Bauchi and B.Eng holder in Electrical/Electronics. She is currently an M.Eng Student in ATBU Bauchi. She supervises and carryout experiments with student. She also handles and stores various laboratory tools and equipment.

DR. MOHAMMED ABDULLAHI is a chief Lecturer at Federal Polytechnic Bauchi. He obtained his Ph.D and specialized on Ruminant Production and Management. He is the pioneer HOD of Animal Health and Production Department. He is the current Dean School of



Agricultural Technology, and also the current Head of Research as well as Head of Technical Committee TETFUND Center of Excellence in integrated Farming at Federal Polytechnic Bauchi. Moreover, he is the Chairman Technical Committee AUDA-NEPAD Africa Project for small scale holders farmers. , Bauchi State

DR. MUHAMMAD YUSUF AGETEGBA is a PhD holder obtained from Sudan University of Science and Technology. He specialized on wireless sensor network and has peer-reviewed journals and conferences. He is currently head of system automation in the IT department of NDIC.

SURV.MUHAMMAD SHEHU KARDAM is a chief lecturer with the Department of Surveying and Geoinformatics. He was the former Head of Department of Surveying and Geoinformatics. A geographic information System Analyst and a current chairman of the Nigerian Institution of Surveyors Bauchi state chapter. He is currently an examiner with the Surveyors Registration Council of Nigeria (SURCON) and team leader in the densification of second order control for the mapping of Bauchi metropolis. He is a Ph.D student with Abubakar Tafawa Balewa University Bauchi and the current Dean School of Environmental Technology Fed. Poly Bauchi.

DR. DAMINA MOHAMMED SADIQ is a Principal Veterinary Research Officer with the National Veterinary Research Institute, Vom, Plateau State.. Dr. Damina is currently a PhD candidate in the Faculty of Veterinary Medicine, Ahmadu Bello University, Zaria working on the Epidemiology of bovine tuberculosis in Adamawa and Gombe States

DR HASSAN BUHARI MAMMAN is a PhD holder and specialized bioelectronic and embedded device (tracker) . He published peer-reviewed journals and conferences of 20 articles.

### **3.3 Research Work to Date**

A.I Arokhamoni, J. Ogunyemi, IH Usman (2022) “Unlocking Programming Skills In Nigerian Youths Through Software Development In Local Languages” Paper presented at Abuja 2022 NSE Conference, November 16<sup>th</sup> 2022.

J. Ogunyemi, A.I Arokhamoni, E.P Ogedengbe (2022) “Comparative Study of World Class and Affordable Software Solutions for Viable Digital and Numeracy Skills Acquisition Schemes in Nigeria” Paper presented at Abuja 2022 NSE Conference, November 16<sup>th</sup> 2022.

I.H Usman, A.M.Y.Jumba, M. A. Yusuf & A. I Arokhamoni (2021). Design, Fabrication and Deployment of Anti-Rustling Tracking System, Journal of African Sustainable Development, Sub-Sahara African Academic Research Publication, 21(2):233 -252

I.H. Usman, N. K. Nordin, E.E Omizegba, A.Sali, M.F.A.Rasid & F.H. Hashim Performance Analyses of Adaptive Handover Decision Algorithm using Spectrum Aggregation in Long Term Evolution-Advanced Network, Proceedings of 2021 26th IEEE Asia-Pacific Conference on Communications, 11th - 13th October, 2021.

I. Aljasawi, I.H. Usman, A.G. Charles & D. M. Nazif. Design and Construction of Four Wheel Drive Robotic Car using an Android Phone Interface, Proceedings of 3rd Annual National Engineering Conference, School of Engineering Technology, Federal Polytechnic Bauchi, 28th - 29th October, 2021

I.H. Usman, U.D Zahraddin, M.A. Ahmad, A. Abdulkadir, A. Mubarak and H. Bala (2021). Design and Construction of an Automatic Phase Failure Detection System for a Three-Phase Motor, International Journal of Engineering and Technology Research, Cambridge Research and Publications International,22(5): 137-148

I.H Usman., Omizegba E.E., Jiya J. D. and Bakare G.A. (2019). Non-Parametric Spectrum Sensing Algorithm for Television White Space Applications, International Journal of Latest Research in Science and Technology, 8(2):13 -18

A.Abdulkadir , I.H.Usman, Sani Maikafi, I. Rufai & A.M.Gadam (2021). Design and Construction of 3.5 KW Self – Loop Generator System, International Journal of Pure and Applied Science, Mediterranean Publications Research International,17(9): 73-80

I.H Usman. & S. Maikafi (2021). Design and Construction of a Microcontroller – Based Fingerprint Attendance System with Wireless Technology, International Journal of Pure and Applied Science, Sub-Sahara African Academic Research Publication, 21(9):123 -130.

I.H Usman., Omizegba E.E., Jiya J. D. & Bakare G.A. (2020). Spectrum Sensing Algorithm for Television White Space Application in Mobile Communication Systems Proceedings of New Direction and Uncommon Changes Sub-Sahara African Nations' Transformation: A Multi-Disciplinary Approach Conference, Vol.11, No. 2, pp 137-153, August, 2020

I.H Usman., Omizegba E.E & L. Maijama'a (2020). Review of Handover Decision Algorithm in Wireless Communication Systems Proceedings of New Direction and

Uncommon Changes Sub-Sahara African Nations' Transformation: A Multi-Disciplinary Approach Conference, Vol.11, No. 3, pp 338-346, August, 2020

I.H Usman., & U.D. Zahraddin (2020). Evolutionary Trends of Wireless Communication Technology: A Review, Proceedings of 4th Virtual National Conference on toward building a knowledge based Society for National Development School of Business Studies Conference Federal Polytechnic Bauchi, 28th October, 2020

Usman I.H., Maikafi S., Kabiru S., & Shaibu H.O. A review of Path loss Estimation Models Applicable to Long Term Evolution Advanced Systems, Proceedings of Academic Staff Union of Polytechnics National Conference, Federal Polytechnic Bauchi 6th - 7th July 2021.

I.H Usman, A.A. Garba and A.M Shehu (2014) Radio Resource Optimization of a GSM Network using Actix Analyzer Service Verification Solution, International Journal of Latest Research in Science and Technology, 3(3): 35-39.(Indexed)

Mohammed, A., Yaro, S.S., Hussaini, N.S., Imam, S.M. and Umar, A.M. (2015). Assessment of farmer's attitude towards sheep management practices in Bauchi metropolis. Presented at the African Scholar Publications and Research Academic Conference, Bauchi State. 10th 13th November, 2015.

Mohammed, A., Umar, A. M., Nyako, H. D., Nuhu, S. H., Yaro, S. S., Oyeniran, J. O., and Ahmad, S. (2020). The performance of Balami Rams fed different supplemental protein sources and a Basal diet of Signal Grass (*Brachiaria decumbens*) Hay. Nigerian society for Animal Production (NSAP) 45th Annual Conference Bauchi – 2020 Book of Proceeding, 15th – 19th March, 1770-1774

Oyeniran, J.O, Nuhu S.H, Mohammed, A, Faniyi, T.O, Mijinyawa, A, Sanga, M.J (2021). Evaluation Of Biosecurity Measures In Some Selected Poultry Farms In Bauchi Metropolis. Proceedings Of 26th Annual Conference Of Asan-Nias, Uyo Nigeria, pg 626-630.

Agetegba, M. Y. (2018). "A Predictive Media Access Control Protocol for Energy Efficient Wireless Sensor Network for E-health Applications" (Doctoral dissertation, Sudan University of Science & Technology).

Agetegba, M. Y., & Lorenz, P. (2017) "Pipeline Monitoring and Spillage Prevention Using Wireless Sensors and High Density Polyethylene Pipe Encasement System" International Journal on Advances in Networks and Services 10,(1): 10,-11

Agetegba, M. Y., & Lorenz, P. “Application of a New Energy-Efficient Protocol for MAC Layer for E-Health”. In Global Communications Conference (GLOBECOM’16), December 2016 IEEE Globecom Journal.

Damina, M. S. (2012): Epidemiology of mycobacteria species in cattle and man in some parts of Plateau State, Nigeria; Master of Veterinary Science (M.V.Sc) research dissertation.

Olabode, H. O. K, Damina, M. S., Ahmed, A. S., Moses, G. D. and Wungak, Y. S. (2012): Retrospective Study of Newcastle disease in commercial poultry farms in Ilorin, Kwara State, Nigeria; Vom Journal of Veterinary Science, 9: 66- 70.

Damina M. S., Owolodun, O. A., Chukwukere S., Ameh J. A. and Aliyu, M. M. (2011): Mycobacterial species identification and public health implications of tuberculosis among nomadic pastoralists in Three Local Government areas of Plateau State, North Central Nigeria; Nigerian Veterinary Journal, 32 (4): 321- 30.

Damina, M. S., Owolodun, O. A., Ameh ,J. A. and Aliyu, M. M. (2011): Molecular Epidemiology of Bovine tuberculosis and most common strains of Mycobacterium bovis in Plateau State, North Central Nigeria; Bull. Anim. Hlth. Prod. Afr. 59 (3): 303- 310.

Damina, M. S., Owolodun, O. A., Chukwukere, S., Ameh ,J. A. and Aliyu, M. M. (2011): The use of deletion analysis in the detection of Mycobacterium bovis, Mycobacterium tuberculosis and Mycobacterium africanum among slaughtered cattle in Plateau State, North Central Nigeria; Nigerian Veterinary Journal, 32 (1): 9- 15.

Owolodun, O. A., Waziri, N. E. and Damina, M. S. (2011): Rifampin and isoniazid Resistance in Tuberculosis Patients, Northwestern Nigeria; Book of Abstract 48th Annual Congress of the Nigerian Veterinary Medical Association, Kwara 2011.

A.I Arokhamoni (2007): “My Book on Computer Studies” Published by Remob International Ventures, 12 Akinde Street, Off AIT Road, Anisere Alagado, Lagos. ISBN: 978-978-082-340-5 (2007).

### **3.4 Previous Research Grants**

Engr Usman Isa Hassan Fabrication and Deployment of Anti-Rustling Tracking System TETFUND Fabrication, 2020

Dr. Mohammed Abdullahi, Nutritive value of some common browse trees in Bauchi state. TETFUND IBR Research Grand, 2018

Dr. Mohammed Abdullahi, Fabrication of Mobile Poultry Brooder TETFUND Fabrication, 2021

### **3.5 Group Research**

ENGR. USMAN ISA HASSAN: Principal Investigator who is Responsible for Management, Leadership, Conduct, Integrity, reporting of the research project, Data Collection from the various semiconductor chip manufacturers, Financial control, Data analysis and Seminars and workshops organization and report writing.

ARTHUR IBUKUNOLUWA AROKHAMONI: Co-Researcher and solution architect. He oversees core hardware and software design, development, integration, implementation and evaluation. He provides external expertise to ensure the project combines the rigor of academia with the quality of the business world. His proficiency covers software development (mobile, web and embedded), database management, server deployment, API integration and documentation of research findings.

DR. MUHAMMAD YUSUF AGETEGBA: Participates as joint contributor and investigator to the findings of the research as a ZigBee WSN expert.

SURV.MUHAMMAD SHEHU KARDAM: Join contributor and investigator to the findings of the research, other responsibilities includes: Proposed farmland mappings with Data Collection and Data Analysis for geo-fencing; system testing, workshop, seminars and report.

DR. MOHAMMED ABDULLAHI: Participate as join contributor and investigator to the findings of the research, Control Animal feed and grazing pattern, taming, inspections, and security and also assists in workshop, seminars and report

DR. DAMINA MOHAMMED SADIQ: Participate as join contributor and investigator to the findings of the research, Data Collection and Data Analysis of periodic check on the cattle health related parameters and drug administration.

DR HASSAN BUHARI MAMMAN: Bioelectronic and embedded device (tracker) fabrication, implantation and supervision.

ENGR. ALIYU ABUBAKAR GARBA: Participate as mentee who will contribute to the findings of the research, Equipment and tools mobilization and storage, Data Collection and Analysis, Testing of the proposed system, workshop, seminars and report

ENGR. FATIMA MUHAMMAD: Participate as mentee who will contribute to the findings of the research serves as Research Office Assistant in charge of office secretarial work, inventory of stationeries, preservation and storage of field data, Data Collection, System Design and Testing of the proposed system, workshop, seminars and report.

### **3.6 Office and Laboratory Space (to be provided by the host institution)**

The Federal Polytechnic Bauchi has agreed to provide office accommodation for the researchers within the school and agreed to give space for taming of test –cattle

### **3.6 Equipment and Materials (to be provided by the host institution)**

The following available software and personnel trainings from the Federal Polytechnic, ICT directorate will be provided.

1. C++ programming
2. Python
3. Java
4. MATLAB

### **3.7 Equipment and Materials available in nearby institutions**

ICT centers, Communication, Electronics, Measurement and Control Laboratories

### **3.8 Other technical support (expected from the host institution)**

The Polytechnic has agreed to provide to the researchers two electrical/electronic technologists to help with the laboratory works.

## **4.0 Financial Aspects of the Research Project Implementation**

### **4.1 Budget Justification**

<b>PERSONNEL COSTS/ALLOWANCE</b>	<b>Budget (₦)</b>	<b>Justification/Remark</b>
Principal Researcher	480,000.00	PI honorarium adjusted from 25,000 to 20,000 per Month
Team Members	2,520,000.00	7 team members honorarium adjusted from 17,142.85 to 15,000
Sub-Total (Not > 20% of budget)	<b>3,000,000.00</b>	
<b>EQUIPMENT (LIST &amp;</b>		

<b>SPECIFY)</b>		
One (1) Printer HP Deskjet 2545 Series	150,000.00	Printing research documents
Two (2) Internet SIM Modem	147,900.00	Internet Modem for researchers and remote cameras
One (1) 3D Printer	670,000.00	3D printer for printing prototype packages, chip moulding
PCB and Flex Circuit Boards	350,000.00	Boards for placing SoC
Surface Mounted Circuit Reflow Oven	877,500.00	For attaching SoC to tracker's PCB boards
Soldering Stereo Microscope	351,000.00	For viewing tiny components while soldering power adapters, batteries etc
Soldering Iron, Paste, Flux	133,854.5	For attaching components to the PCB
Sub-Total (Not > 25% of budget)	<b>2,680,254.5</b>	
<b>SUPPLIES/CONSUMABLES</b>	<b>Budget (₦)</b>	<b>Justification/Remark</b>
Internet Subscription on 2 Modems	5,000.00	Data subscription for two years on two modems
Server for Hosting Web Application	500,000.00	For hosting tracker's and geofencing database web applications
Google Maps License	210,600.00	Using Javascript API - static map
Fabrication Mould	-	Adjusted, packages will be designed using 3D printer
Tracker SoC Design	300,000.00	Cost of designing SoC device before die casting
SoC Manufacturing	8,334,860.00	Cost of manufacturing multiple tracker SoC chips on wafer
Enterprise Database License	1,150,000.00	Database license for multi-core hosting server
Batteries for Proposed Trackers	2,062,854.50	Units of 450-1000mAh batteries
Sub-Total	<b>12,563,314.50</b>	
<b>DATA COLLECTION &amp; ANALYSIS</b>	<b>Budget (₦)</b>	<b>Justification/Remark</b>
Data Collection	150,000.00	To collect and collate information on individual chip sizes, minimum SoC or SiP sizes and enterprise database performance
Sub-Total	<b>150,000.00</b>	
<b>DISSEMINATION</b>	<b>Budget (₦)</b>	<b>Justification/Remark</b>

Local Conferences	400,000.00	Conferences with stakeholders
Sub-Total (Not >3%)	<b>400,000.00</b>	
<b>OTHERS/MISCELLANEOUS</b>	<b>Budget (₦)</b>	<b>Justification/Remark</b>
Administrative Running Costs	206,431.00	Stationeries and office supplies
Sub-Total	<b>206,431.00</b>	
<b>INDIRECT COST</b>	<b>Budget (₦)</b>	<b>Justification/Remark</b>
5 % to Host Institution	<b>1,000,000.00</b>	Host Institution assigned percentage
<b>GRAND-TOTAL</b>	<b>20,000,000.00</b>	



## REFERENCE

1. Chiluiwa, Innocent, and Isioma M. Chiluiwa. (2020): "'Deadlier than Boko Haram': Representations of the Nigerian herder–farmer conflict in the local and foreign press." *Media, War & Conflict* 1750635220902490.
2. National Bureau of Statistics "Selected Food Price Watch (April 2022)"
3. Vanger, Emmanuel Terngu (2021) "Insurgency and Counterinsurgency: Understanding the Patronage Politics of the Nigerian State." *Fudma Journal of Politics and International Affairs* 4.1: 76-93.
4. Olanrewaju, Opeyemi, Romanus Osabohien, and James Fasakin. (2020). "The Anchor Borrowers Programme and youth rice farmers in Northern Nigeria." *Agricultural Finance Review*
5. Tobi, Bright E. (2022)"Fear, Distrust and the Political Climate of the Rural Grazing Area (Ruga) Policy in Nigeria." *Rural and Urban Violence in Nigeria*. 67
6. Anene, Chidi P., and Theodore O. Iyala. (2020). "Failure of Ranching Policies In Nigeria: Proposed Cattle Colony And Ruga Settlement in Perspective, 1914-2018." *Igwebuike: African Journal of Arts and Humanities* 6:6
7. Aidonojie, Paul Atagamen, Omohoste Patience Agbale, and Oluwaseye Oluwayomi Ikubanni. (2021) "Analysing the land use act, the grazing reserves act and the proposed Fulani cattle colonies (RUGA settlement) and NLTP." *Nnamdi Azikiwe University Journal of International Law and Jurisprudence* 12: 138-148.
8. Gwatorisa, C., (2022):. "Microhabitat and patch selection detection from GPS tracking collars of semi-free ranging Mashona cattle within a semi-arid environment." *Livestock Science* 104963.
9. Ilyas, Qazi Mudassar, and Muneer Ahmad. (2020). "Smart farming: an enhanced pursuit of sustainable remote livestock tracking and geofencing using IoT and GPRS." *Wireless communications and mobile computing*
10. Usman I.H., Arokhamoni A. I., Yusuf M. A. & Jumba A.M.Y. (2021). "Design, Fabrication and Deployment of Anti-Rustling Tracking System", *Journal of African Sustainable Development, Sub-Sahara African Academic Research Publication*, 21(2):233 -252.
11. Badamasi, Saidu. (2020) "Loss of Intergroup Relation and Conflict Escalation: The Case of Farmer-Herder Conflicts in Kaduna State, Nigeria."

12. Odalonu, Boris Happy (2020). "Appraisal of the Political and Socio-Economic Effects of Farmers-Herders Conflict in Uzo-Uwani Local Government Area of Enugu State, Nigeria." *Journal of Alternative Perspectives in the Social Sciences* **10**:3
13. Ali, Mr Ershad. "Global Positioning System (GPS): (2020). Definition, Principles, Errors, Applications & DGPS."
14. Hsu, Li-Ta. (2018) "Analysis and modeling GPS NLOS effect in highly urbanized area." *GPS Solutions* 22 (1): 1-12.
15. Foley, Conrad J., and Claudio Sillero-Zubiri (2020) "Open-source, low-cost modular GPS collars for monitoring and tracking wildlife." *Methods in Ecology and Evolution* 11 (4 ):553-558.
16. Lemes, Júlio Cesar, (2020). "Influence of pitch size and age category on the physical and physiological responses of young football players during small-sided games using GPS devices." *Research in sports medicine* 28(2): 206-216.
17. Waqar, Adnan, et al. (2021) "Analysis of GPS and UWB positioning system for athlete tracking." *Measurement: Sensors* 14: 100036.
18. Dempsey, P. (2020)"Reviews-Consumer Technology. The Teardown-Samsung Galaxy Watch 3." *Engineering & Technology* 15(10): 84-85.
19. Martinez, D. "Samsung Galaxy Watch Dimensions & Drawings". Retrieved September 25, 2021, from <https://www.dimensions.com/element/samsung-galaxy-watch>. (2020, April 9).
20. Martinez, D. "Huawei Watch Dimensions & Drawings". Retrieved September 25, 2021, from <https://www.dimensions.com/element/huawei-watch> (2020, April 9).
21. Martinez, D. "Huawei band 3 Dimensions & Drawings". Retrieved September 25, 2021, from <https://www.dimensions.com/element/huawei-band-3> (2020, April 9).
22. Awotokun, Kunle, Agaptus Nwozor, and John Olanrewaju. (2020): "Conflicts and the Retrogression of Sustainable Development: The Political Economy of Herders-Farmers' conflicts in Nigeria." *Humanities & Social Sciences Reviews* 8 (1): 624-633.
23. Kozuch, Kate. "Samsung Galaxy Watch 4 Battery Life - What We Hope to See." *Tom's Guide*, Tom's Guide, 23 July 2021, <https://www.tomsguide.com/news/samsung-galaxy-watch-4-battery-life-what-we-hope-to-see>.
24. Karl, Jason W., and James E. Sprinkle. (2019): "Low-cost livestock global positioning system collar from commercial off-the-shelf parts." *Rangeland Ecology & Management* 72(6): 954-958.

25. Clark, Patrick E., et al. (2006): "An advanced, low-cost, GPS-based animal tracking system." *Rangeland Ecology & Management* 59 (3) 334-340.
26. Bailey, Derek W., et al. (2021)"Opportunities to apply precision livestock management on rangelands." *Frontiers in Sustainable Food Systems* 5(6): 915.
27. Akbar, Muhammad Osama, et al. (2020). "IoT for development of smart dairy farming." *Journal of Food Quality*
28. Afrianto, Irawan, Sri Wahjuni, and Taufik Djatna. (2020). "Model of Ubiquitous Precision Livestock System 4.0: A Technological Review." *FoITIC* 156-162.
29. Shalf, John. "The future of computing beyond Moore's law. (2020)." *Philosophical Transactions of the Royal Society A* 378.2166 (2020): 20190061.
30. GlobalSat WorldCom Corp. "Cattle Tracking Solution." GlobalSat WorldCom Corp., GlobalSat WorldCom Corporation, Globalsat.com.tw 2018. Retrieved 9 June 2022.
31. Thales Group. "What is eSIM? Explained." Thalesgroup.com 2022. Retrieved 9 June 2022.
32. Grayson, Brian, et al. "Evolution of the Samsung Exynos CPU Microarchitecture" 2020 ACM/IEEE 47th Annual International Symposium on Computer Architecture (ISCA). IEEE, 2020.
33. Bogdan Solca. "TSMC already sampling Apple's 5 nm A14 Bionic SoCs for 2020 iPhones" NotebookCheck.net News, 2019. Retrieved 13 June 2022.
34. Patel, Dylan (27 October 2020). "Apple's A14 Packs 134 Million Transistors/mm<sup>2</sup>, but Falls Short of TSMC's Density Claims". *SemiAnalysis*. Retrieved 13 June 2022.
35. Samsung Electronics Co., Ltd (10 August 2021). "Samsung Introduces the Industry's First 5nm Processor Powering the Next Generation of Wearables". *Samsung.com News*. Retrieved 13 June 2022.
36. Samsung Electronics Co., Ltd (2021). "Samsung Announces Game Changing Exynos 2200". *Samsung.com News*. Retrieved 13 June 2022.
37. Samsung Electronics Co., Ltd (2021). "Samsung Introduces the Industry's First 5nm Processor Powering the Next Generation of Wearables". *Samsung.com News*. Retrieved 13 June 2022.
38. Adrion, Felix. (2018). "Adaption and assessment of a UHF-RFID system for livestock management."
39. Ryabtsev, V. G., and S. V. Volobuev. (2020) "Implementation of Memory in a System on a Chip with Built-In Self-Testing and Self-Healing." *Russian Microelectronics* 49(7): 527-531.

40. Sumukh Rao, (March 18th, 2019). "What's an SiP and How does it Differ from an SoC?: Wondering about Qualcomm Snapdragon SiP 1?". [www.techpp.com](http://www.techpp.com). Retrieved 13 June 2022.
41. Santosh Das, (July 17, 2021). "Double Sided PCB | Types of PCB". [www.electronicssandy.com](http://www.electronicssandy.com). Retrieved 15 June 2022.
42. Santosh Das, (July 17, 2021). "Multilayer PCB | Types of PCB". [www.electronicssandy.com](http://www.electronicssandy.com). Retrieved 15 June 2022.
43. Surana, P., Madhani, N., & Gopalakrishnan, T. (2020). "A Comparative Study on the Recent Smart Mobile Phone Processors". In 2020 7th International Conference on Smart Structures and Systems (ICSSS) (pp. 1-3). IEEE.
44. Agetegba, M. Y. (2018). "A Predictive Media Access Control Protocol for Energy Efficient Wireless Sensor Network for E-health Applications" (Doctoral dissertation, Sudan University of Science & Technology).
45. OriginGPS. (2020). "Nano Hornet - ORG1411 Evaluation Kit Datasheet". Revision 4.5, 26.
46. u-blox. (2021). "MPCI-L2 Series: Multi-mode LTE Cat 4 Mini PCIe modules with HSPA+ and/or 2G fallback". Revision 27, 7.
47. Li, Yan, et al. "Passive-zigbee: Enabling zigbee communication in iot networks with 1000x+ less power consumption." Proceedings of the 16th ACM conference on embedded networked sensor systems. 2018.
48. Adi, Puput Dani Prasetyo, and Akio Kitagawa (2019). "Quality of Service and power consumption optimization on the IEEE 802.15. 4 pulse sensor node based on Internet of Things." International Journal of Advanced Computer Science and Applications (IJACSA) 10 (5): 144-154.
49. Santosh Das, (2021). "Multilayer PCB | Types of PCB". [www.electronicssandy.com](http://www.electronicssandy.com). Retrieved 15 June 2022.
50. Adrion, Felix, et al. "Setup, test and validation of a UHF RFID system for monitoring feeding behaviour of dairy cows." Sensors 20(24): 7035.
51. Abdullahi, U. S., et al. (2019): "Exploiting IoT and LoRaWAN technologies for effective livestock monitoring in Nigeria." Arid Zone Journal of Engineering, Technology and Environment 15.SPi2 146-159.
52. Xu, Beibei, et al. (2020): "Livestock classification and counting in quadcopter aerial images using Mask R-CNN." International Journal of Remote Sensing 41(21) : 8121-8142.

53. Ngo, Ha Quang Thinh, Thanh Phuong Nguyen, and Hung Nguyen (2020): "Research on a low-cost, open-source, and remote monitoring data collector to predict livestock's habits based on location and auditory information: a case study from Vietnam." *Agriculture* 10(5) 180.
54. Nyamuryekung'e, S., et al. (2022). "Performance of Lora-WAN Sensors for Precision Livestock Tracking and Biosensing Applications."
55. Tedeschi, Luis O., Paul L. Greenwood, and Ilan Halachmi. (2021): "Advancements in sensor technology and decision support intelligent tools to assist smart livestock farming." *Journal of Animal Science* 99(2) skab038.